A house of cards: Bias in perception of body size mediates the relationship between voice pitch and perceptions of dominance

Armstrong MM[1], Lee AJ[2], Feinberg DR[1*]

1. Department of Psychology, Neuroscience, & Behaviour
McMaster University
1280 Main St West,
Hamilton ON L8S 4K1
Canada

2. Institute of Neuroscience and Psychology
University of Glasgow
62 Hillhead Street
Glasgow, Scotland UK

* Author to whom all correspondence should be addressed

Word count: 8509

ABSTRACT

Theories of the evolution of low voice pitch in men are based on the idea that voice pitch is an honest indicator of physical dominance, but relationships among pitch, physical body size and strength among same sex adults voice are weak and unstable. Nevertheless, judgements of body size based on voice pitch are the result of perceptual bias that low frequencies sound large. If dominance judgements are based in part on perception of size, then dominance perception could also be the result of perceptual bias. Thus, we tested if the relationship between voice pitch and judgements of height mediated the relationship between voice pitch and dominance judgements. The relationship between voice pitch and perceived height fully mediated the relationship between voice pitch and dominance. This was driven by the portion of variance that was inaccurate in height perception (i.e. residual error), and not conditional upon actual height, or perceptions thereof. Collectively our results demonstrate that the relationship between voice pitch and perceived dominance is not based on observation of real world relationships between physical size and voice pitch, but rather based on a bias to perceive low pitched voices as large people. Hence, the relationship between dominance and voice pitch is coincidental rather than causal. Thus, since the relationship between physical dominance and voice pitch is conditional upon the relationship between a biased perception of body size, voice pitch is not an honest indicator of physical dominance. Consequently, the evolution of low pitch in men's voices cannot be explained by selection for accurate dominance cues.

`

INTRODUCTION

It is an evolutionary stable strategy for animals to display secondary sexual characteristics in competitive scenarios to indicate dominance in such a way as to reduce costs associated with physical fights over access to resources (Maynard Smith & Price, 1973). One category of such displays is vocalizations. Vocal indicators of dominance are used in hundreds of species across the animal kingdom (Andersson, 1994), including among humans (Borkowska & Pawlowski, 2011; Cowan, Watkins, Fraccaro, Feinberg, & Little, 2015; Doll et al., 2014; Feinberg et al., 2006; Feinberg, 2008; Han et al., 2017; Jones, Feinberg, DeBruine, Little, & Vukovic, 2010; Puts, Hodges, Cárdenas, & Gaulin, 2007; Puts, Gaulin, & Verdolini, 2006; Vukovic et al., 2011). Voice pitch (the perception of fundamental frequency and its harmonics), and/or formant frequencies (the resonant frequencies of the supralaryngeal vocal tract) are used by many species to indicate body size (Bowling et al., 2017), the primary indicator of physical dominance (Darwin, 2004; Trivers, 1976). Voice pitch and formant frequencies are used as indicators of dominance, but do they relate to physical measures of the primary indicators of physical dominance: body size and strength? The aim of our study was to test if the relationship between voice pitch and dominance perceptions is based on the false perception that tall people have low pitched voices.

Pitch

A physical property of sound is that larger objects produce sounds that have longer wavelengths, and hence lower frequencies (Titze, 1994). However, this phenomenon does not de facto translate to bioacoustics because most terrestrial mammals, including humans, produce sound by vocal fold vibrations. The vocal folds are soft tissue and can grow independently of the rest of skeletal structure (Fitch, 1997) and sound is determined by the size and thickness of the vocal folds. Across species, larger animals produce lower-pitched sounds (Bowling et al., 2017; Hauser, 1993; Martin, Tucker, & Rogers, 2017). Within the same species, pitch is related to body size, and used in dominance assessments, among Humboldt penguins *(Spheniscus humboldti*) and Magellanic penguins *(Spheniscus magellanicus)* (Favaro, Gamba, Gili, & Pessani, 2017), common toads (*Bufo bufo*) (Davies & Halliday, 1978), as well as many other species. Voice pitch is perceived to scale allometrically with height in same sex adults (Feinberg, Jones, Little, Burt, & Perrett, 2005; Pisanski & Rendall, 2011; Rendall, Vokey, & Nemeth, 2007; Smith & Patterson, 2005), but meta-analyses of human height and voice pitch show that there is no relationship between voice pitch and height or weight among same-sex human adults (Pisanski et al., 2014b; Pisanski et al., 2015).

In humans, voice pitch is linked to pubertal testosterone levels (Harries, Hawkins, Hacking, & Hughes, 1998), and this relationship remains stable throughout adulthood (Fouquet, Pisanski, Mathevon, & Reby, 2016). While testosterone is not a proxy for height (Tremblay et al., 1998) or strength (Fahey, Rolph, Moungmee, Nagel, & Mortara, 1976), it builds muscle by increasing the rate of protein synthesis (Griggs et al., 1989). While body size is the primary indicator of physical dominance, physical strength is also very important, especially when individuals are closely matched in size, as the purpose of signalling size and strength is to minimize the costs of direct aggression (Maynard Smith & Price, 1973). Several studies have tried to find a link between voice pitch and physical strength, but the results are weak and do not typically replicate. Three independent lab groups were unable to find any link between voice pitch and physical strength measures among adults (Han et al., 2017; Sell et al., 2010; Smith, Olkhov, Puts, & Apicella, 2017). Out of several published samples on adults, only one reports that voice pitch is negatively related to physical strength (Puts, Apicella, & Cárdenas, 2012), however, these results were weak and only significant when not controlling for multiple comparisons (Bakker, Hartgerink, Wicherts, & van der Maas, 2016). Thus, there is no evidence to support the idea that voice pitch indicates physical strength among same-sex adults.

Formants

Formant frequencies are the resonant frequencies of the supralaryngeal vocal tract (henceforth: vocal-tract) (Titze, 1994). Formants are thought to relate to body size because larger individuals typically have longer vocal tracts (Fitch & Giedd, 1999; Sulter et al., 1992). Among humans, estimates of vocal tract length from formant frequencies at best explain 10-15% of the variance in human body size among same-sex adults (Pisanski et al., 2014b; Pisanski et al., 2015). About 75% of the explanatory power in height is lost when vocal-tract length is estimated from formant frequencies as opposed to measured in MRI. Even more of this explanatory power is lost when these formants translate into size assessments because of the interaction between fundamental and formant frequencies on size perception (Smith & Patterson, 2005), and other biases in height perception such as the “low is large” heuristic (Pisanski, Isenstein, Montano, O’Connor, & Feinberg, 2017), whereby playing low pitched voices closer to the ground makes them sound larger than when played from higher up in spatial location.

`

Subjective vs. Objective Measures of Dominance

Studies have shown that in natural voices, voice pitch and formant frequencies are negatively tied to both perceptions of body size and dominance (Doll et al., 2014; Han et al., 2017; Hodges-Simeon, Gaulin, & Puts, 2011; Jones et al., 2010; Puts et al., 2007; Vukovic et al., 2011).

In natural voices, ratings of size correlate negatively with both pitch and formant frequencies (Collins, 2000; Rendall et al., 2007). Although the two frequency components interact when people make size and attractiveness judgements (Feinberg et al., 2011; Smith & Patterson, 2005), even when controlling for pitch in natural voices, formants still negatively predict perceived body size (Rendall et al., 2007). Furthermore, lowering both pitch and formants together and independently increases perceived size in men's voices (Feinberg et al., 2005; Smith & Patterson, 2005). The focus of most of these studies has been men's voices, and little data exist on the relationship between voice frequencies and *perceived* body size in women's voices. In these studies (Pisanski, Mishra, & Rendall, 2012; Pisanski & Rendall, 2011; Rendall et al., 2007), formants are perceived similarly among women's and men's voices with respect to dominance and size.

In addition to altering perceived body size, lowering pitch and formant frequencies together and independently also increases perceived physical and social dominance (Feinberg et al., 2006; Jones et al., 2010; Puts et al., 2006). Men will lower the pitch of their voice in response to a competitive scenario, although formants were not studied in this context (Puts et al., 2006). Across cultures, people also lower their pitch and formants when volitionally trying to sound larger (Pisanski et al., 2016).

Although there is no link between voice pitch and physical dominance indicators, voice pitch may still predict objective measures of social dominance. Both men and women with lower pitched voices are perceived to be better political candidates, and are more likely to actually win political elections (Gregory Jr & Gallagher, 2002; Klofstad, 2016; C. A. Klofstad, Anderson, & Peters, 2012; Pavela Banai, Banai, & Bovan, 2017; Tigue, Borak, O’Connor, Schandl, & Feinberg, 2012). Furthermore, men and women with lower pitched voices tend to have higher paying, more prestigious jobs with leadership roles (Klofstad et al., 2012; Mayew, Parsons, & Venkatachalam, 2013).

Despite the weak link between voice pitch and physical markers of formidability, dominance, and the likelihood of winning dominance bouts, there is a growing body of literature suggesting the idea that sex difference in voice pitch evolved via male-male competition, because voice pitch has a very strong effect on dominance ratings (Doll et al., 2014; Hodges-Simeon et al., 2011; Puts, 2016; Puts, 2010; Puts et al., 2012; Puts et al., 2006; Puts et al., 2016; Puts et al., 2007). Given the lack of relationship between objective physical markers of dominance and voice pitch, we tested if perceived height, measured height, and the residuals of perceived and measured height (i.e. residual error in height perception) mediated the relationship between putative vocal indicators of size and dominance (i.e. pitch and formant frequencies), and dominance perception. Following previous work (Puts et al., 2006), we separated dominance into physical and social categories and asked both men and women to rate men and women’s voices for dominance (physical and social) and height. We then tested whether body size (perceived, measured, and residual error in perceived height) were mediators of the relationship between pitch and dominance, and formants and dominance, independently. Since the aforementioned work shows that the links among voice pitch, formants, and perceived body size are much stronger than the links among these voice qualities and physical size measurements, we predict that the discrepancy in size perception versus physical size could affect perceptions that depend on body size perception, such as dominance. We predict that perceived size, and residual error in size attribution will mediate the relationship between voice frequency (pitch/formants) and body size (perceived, residual error, and measured). Here measured height serves as an ideal observer control condition, meaning that if people were 100% accurate in height perception from the voice, their data would be statistically identical to measured height. If measured height has little to do with perceived body size from the voice, then we do not expect measured height to mediate the relationship between pitch and formants, and dominance.

METHODS

All protocols were approved by the McMaster University Research Ethics Board.

Stimuli

From a larger database of peer-aged voices recorded at McMaster University, Hamilton, Ontario, Canada (Pisanski et al., 2014b), we used recordings of 108 women ages 17 to 30 and 74 men ages 17 to 30. Six people opted to not report their age. Each speaker was recording saying the English monophthong vowels /ɑ/, /ɛ/, /i/, /o/, and /u/.

Recordings were made in an anechoic sound-controlled booth (WhisperRoom Inc. SE 2000 Series Sound Isolation Enclosure), with speakers standing approximately 5-10 cm from the Sennheiser MKH 800 studio condenser microphone with a cardioid pick-up pattern. An M-Audio Fast Track Ultra interface was used to digitally encode the audio at a 96 kHz sampling rate and 32-bit amplitude quantization. Files were stored onto a computer as PCM WAV files using Adobe Soundbooth CS5 version 3.0. We used the root mean squared method to normalize voices to 70dB SPL. Vowels for each voice were presented in a consistent order, separated by 350 ms of silence. The voices used in this experiment were selected on the criteria that they were the largest available set of voices for which we had physical measurements of their height and weight (as opposed to self-report), and were recorded under the same conditions with the same equipment, speaking the same sounds. This sample size is larger than some studies (Collins, 2000; Collins & Missing, 2003), and comparable to others (Puts et al., 2006).

Height/Ideal Observer Measurement

As noted in Pisanski et al., 2014b, speakers' heights were measured in cm with metric tape affixed to a wall. Women ranged from 151.5 to 183 cm tall (mean=164.7cm, SD=7.11 cm), and men ranged from 167 to 191 cm tall (mean=177.7 cm, SD=6.50 cm).

Voice Measures

The voices used in this experiment were previously analysed for voice pitch and apparent vocal tract length (Pisanski et al, 2014b). Briefly, we used the autocorrection algorithm in Praat software (Boersma & Weenink, 2013) with a range of 65 Hz–300 Hz for male voices and 100 Hz–600 Hz for female voices to determine the average fundamental frequency (the physical correlate of pitch) of each voice. The first four formant frequencies (F1–F4) were measured using the Burg Linear Predictive Coding (LPC) algorithm in Praat (Boermsa & Weenink 2013) with a maximum formant setting of 5000 Hz for male voices and 5500 Hz for female voices. The formants were superimposed on a spectrogram and then the formant number was manually adjusted to achieve the best visual match of predicted and observed formants. The mean values for F1–F4 were used to calculate the apparent vocal tract length (henceforth VTL) (Reby & McComb, 2003), which has previously been shown be a relatively accurate method of estimating vocal-tract length in men's voices (Pisanski et al., 2014b).

Procedure

Participants listened to a series of voices played on Sennheiser HD 280 Pro over-ear headphones, played at a consistent volume set prior to the experiment. We used PsychoPy (Peirce, 2007) to present stimuli and record responses. Male and female voices were presented in separate blocks. In each male block, participants rated each of the 74 voices, and in each female voice block, participants rated each of the 108 voices. The order of voices within each block, as well as the rating attribute for each block, was randomized. Participants chose to complete 1, 2, or 3 blocks of ratings. Most participants completed 3 blocks. Our design contains a mix of within and between-subjects data. Voices were rated for one of the following attributes: height (1=very short; 7=very tall) social dominance, defined as "A socially dominant person tells other people what to do, is respected, influential, and often a leader; whereas submissive people are not influential or assertive and are usually directed by others." (1=very submissive;

7=very dominant) (adapted from Mazur, Halpern, & Udry, 1994); physical dominance, defined for male voices as “A physically dominant person is someone who if they were in a fist fight with an average undergraduate male, they would probably win.” and similarly for female voices as “A physically dominant person is someone who if they were in a fist fight with an average undergraduate female, they would probably win.” (1=very submissive; 7=very dominant) (adapted from Puts et al., 2006).

Gender was self-reported. We assessed gender by asking participants to: “Please indicate your gender by typing the number that corresponds to your gender. 0 = female, 1 = male, 2 = transgender, 3 = other, s = skip”. No participants reported they were transgender or other gender, thus we assumed our sample was cisgender.

Participants

We recruited students using McMaster University’s online Research Participation System. Participants provided informed consent and were compensated with either course credit or $10 Canadian per hour, *pro rata*. Table 1 shows the breakdown of number of raters and their ages per condition.

Table 1 around here

`

Statistical Analyses

All statistical analyses were conducted in R statistical analysis software. Although each block had different numbers of participants, there was very high agreement between raters (All Chronbach's alpha calculated separately for each sex and rating > 0.9).

First, using linear mixed effects modelling, we tested whether the association between voice pitch and dominance ratings (physical and social) decreased when adding one of the three height measurements (perceived height, measured height, and inaccurate height) into the model. Linear mixed effects models were conducted using the *'lme4'* (Bates, Mächler, Bolker & Walker, 2015) and *'lmerTest'* (Kuznetsova, Brockhoff & Christensen, 2015) packages for the R statistical software. Separate models were conducted for physical and social dominance ratings, and for each height measurement, and also repeated using VTL as a predictor instead of voice pitch, resulting in 12 separate models. For each model, random intercepts were specified for each audio stimulus and for each participant to control for non-independence of ratings of the same stimulus and from the same participant respectively. Random slopes were specified maximally as suggested in Barr et al. (2013) and Barr (2013). Models where introducing height as a predictor reduced the predictive power of voice pitch indicate that there is a potential mediating effect of height; therefore, this was further investigated via mediation analysis using the '*mediation'* package in R (Tingley, Yamamoto, Hirose, Keele & Imai (2014). Due to limitations in the R 'Mediation' package, we were unable to include both random effects groups specified in a multilevel mediation analysis above. Therefore we only included random effects group of participant in the mediation analyses. For all analyses above, we z-scored each variable at the appropriate group level (i.e. voice identity for perceived and false height, voice pitch, VTL, and measured height). We effect-coded participant sex (-0.5 for cis-gendered females and 0.5 for cis-gendered males). We report fixed effects for models here. For mediation models, we report only the proportion mediation (PM). Full output, model specifications, and scripts can be found in supplementary electronic material. We conducted power analyses on all mediation models and found that in each case, for voice pitch analyses (our primary interest here), our power approached 1 (Kenny, 2017).

To determine how accurately people could assess height from the voice alone, we created two multilevel models (one for female and one for male voices) with perceived height as the dependent variable, measured height as the predictor, participant sex as a fixed effect, and participant identity as a random effects level.

RESULTS

Measured, Perceived, and Inaccurate Height

There was an effect of measured height on perceived height (male voices: estimate=0.323, s.e.=0.0249, t_{83}=12.958, p<0.0001; female voices: female voices: estimate=0.10287, s.e.=0.01400, t_{88}=7.450, p<0.0001). There was a small effect of sex of participant for male voices (estimate=-0.189, s.e.=0.0848, t_{83}=-2.238, p<0.0279), but not female voices. In neither case was there an interaction between sex of participant and measured height. We saved the residuals from these models and labelled the mean residuals for each stimulus' ‘inaccurate height perception' because it represents the residual error in accuracy in height perception across raters. Plots of measured height vs inaccurate height shows a random distribution of slopes across participants and no discernible relationship between measured height and the inaccurate height perception variable, as well as no discernible sex difference in this relationship (see supplementary online material).

Voice Pitch

Voice Pitch and Height

Linear regression demonstrated that there was no significant relationship between fundamental frequency and measured height for female voices (*B*<0.001, $t(106)=-0.010$, $p=0.992$, $R^{2}<0.001$), but there was an association between fundamental frequency and measured height for male voices (*B*=-0.156, $t(72)=-3.674$, $p<0.001$, $R^{2}=0.158$). These results are both within the normal distribution of expected effect sizes given in a recent meta-analysis (Pisanski et al., 2014b). Fundamental frequency significantly predicted perceived height for both female voices (*B*=-0.022, $t(106)=-8.911$, $p<0.001$, $R^2=0.428$) and male voices (*B*= -0.034, $t(72)=-13.302$, $p<0.001$, $R^{2}=0.711$).

Mediation Analysis

Mediation analyses investigated whether height perception mediates the relationships between voice pitch/formant frequencies and perceived physical/social dominance. Here our models are 1-1-1 multilevel mediation models, where predictor, mediator, and outcome all occur at level 1. Figure 1 is a graphic description of our models.

Figure 1 around here

We performed separate mediation analyses using perceived height, measured height, and inaccurate height perception as potential mediating variables. Mediation analyses were conducted using 1000 bootstrap samples and 95% Confidence Intervals. Full results are found in the Supplementary Information. No differences in confidence interval significance level were found when using 10,000 vs 1000 bootstraps. We used 1000 bootstraps here due to computation limitations. Here we only report percent mediation (PM) from mediation analyses from models where including a height variable decreased the predictive power of voice pitch or vocal-tract length on dominance perception (either physical or social). In all models we included sex of rater as a fixed effect.

Since other work has found that lower pitch increases accuracy of formant-based size judgements (Pisanski, Fraccaro, Tigue, O'Connor, & Feinberg, 2014), we also included either VTL or voice pitch (respectively) as a covariate in the mediation analyses to control for any potential effects here. Table 2 displays Proportion mediated and 95% confidence intervals from significant mediation analyses. Full mediation analyses, outputs, scripts, and models can be found in the supplementary online materials. Proportion mediated results greater than 1 indicate models where suppression occurred.

Table 2 around here

<u>Table 2</u>

Dominance Type	**Sex Of Voice**	**Height Variable**	**Voice Quality**	**Proportion Mediated**	**Lower CI**	**Upper CI**
Physical	Female	Inaccurate	Pitch	0.582	0.524	0.65
Physical	Female	Measured	Pitch	0.0182	0.0104	0.03
Physical	Female	Perceived	Pitch	0.8440	0.7794	0.92
Physical	Male	Inaccurate	Pitch	0.579	0.520	0.65
Physical	Male	Measured	Pitch	0.01771	0.01063	0.03
Physical	Male	Perceived	Pitch	0.8423	0.7790	0.91
Social	Female	Inaccurate	Pitch	0.526	0.458	0.60
Social	Female	Measured	Pitch	0.0244	0.0134	0.04
Social	Female	Perceived	Pitch	0.0244	0.0134	0.04

Social	Male	Inaccurate	Pitch	0.525	0.464	0.60
Social	Male	Measured	Pitch	0.0243	0.0137	0.04
Social	Male	Perceived	Pitch	0.8421	0.7706	0.92
Physical	Female	Inaccurate	VTL	0.7524	0.6348	0.92
Physical	Female	Measured	VTL	0.3300	0.2554	0.42
Physical	Female	Perceived	VTL	1.4288	1.2061	1.74
Physical	Male	Inaccurate	VTL	0.7484	0.6244	0.91
Physical	Male	Measured	VTL	0.3326	0.2579	0.43
Physical	Male	Perceived	VTL	1.4242	1.2139	1.77

Physical vs acoustic measures

One potential explanation for our results is that they are an artefact of how the variables were measured (ratings scales show stronger associations whereas non-rating measures, acoustic and physical measures, show weaker associations). Indeed, the relationship between voice pitch and social dominance ratings ($r(74)=0.690$) is not significantly different than the relationship between perceived height and social dominance ratings ($r(74)=0.735$; Fischer's R to Z, $z= 0.55$, $p=0.582$). Therefore, the aforementioned idea cannot explain our results.

DISCUSSION

We found that perceived height fully mediated the relationship between voice pitch and judgements of dominance. In other words, dominance ratings can be explained fully by the relationship between voice pitch and our perceptions of body size. Consistent with other research, we found that perceptions of body size from the voice were reasonably accurate (Bruckert, Liénard, Lacroix, Kreutzer, & Leboucher, 2006; Collins, 2000; González, 2003; Pisanski et al., 2014a; Rendall et al., 2007; van Dommelen & Moxness, 1995). Here we can explain 21% of the variance in body size from people's ratings of men's voices. However, we determined that for both women's and men's voices, the residual error or portion of the variance in people's height ratings that is incorrect (i.e. based on bias) plays a larger role in determining how dominant people sound than the proportion of variance in perceived height explained by measured height, or what could be observed. This suggests that judgments of dominance based on pitch of voice are based on bias rather than observation of the physical world. If judgements of dominance were based on a physical relationship between voice pitch and body size, we would have expected data from the ideal observer to mediate the relationship between voice pitch and height. This did not happen. Instead, it was the inaccurate portion of the variance in perceived height that mediated the relationship between dominance and voice pitch. Even though people can judge body size from the voice to some degree of accuracy in men's voices, this information is not used when rating the dominance of voices. Instead, our results show that dominance ratings of voices are based on a bias to think that people with low-pitched voices are tall.

Types of ratings

The inaccurate portion (i.e. residual error) of our perception of body size partially mediated the relationship between voice pitch and dominance. In fact, data from an ideal observer (i.e. physical height measurements), who would perceive body size from the voice with 100% accuracy, mediated these relationships even less than did the false height variable. Thus, the inaccurate perception of size drives perceptions of dominance, rather than the component of the relationship between perceived and actual size that is accurate. Therefore, we suggest that ratings of dominance are based on the bias that low pitch originates from tall people and that this bias is what makes us think that people with low voices are more dominant. Our findings show no support for the idea that dominance ratings are causally related to measured physical size (Hodges-Simeon et al., 2011; Puts et al., 2016; Puts et al., 2007). This has implications for theories that evolution of low voice pitch in men is due to male-male competition (Puts et al., 2016), as voice pitch can no longer be thought of as an honest indicator of physical dominance. Consequently, we suggest that future theories of the evolution of low voice pitch in men focus on sensory bias, rather than honest or costly signalling.

Sensory exploitation theories of sexual selection suggest that males with traits that effectively stimulate sensory systems are relatively more successful (see Feinberg, Jones, & Armstrong, in press, for review). Over evolutionary time, selection ramps up the frequency and size of those traits via female choice (Ryan & Keddy-Hector, 1992). In the sensory exploitation theory of sexual selection, preferences for traits do not have to be adaptive on their own (Dawkins & Guilford, 1996), but can be by-products of neural responses that evolved to deal with different evolutionary pressures (Johnstone, 1995). Almost all hearing species react to low-frequency sounds as if they are potentially large or threatening (Owings & Morton, 1998). There are no special circumstances to suggest otherwise for our lineage; therefore, it is reasonable to suggest that there is a sensory bias that low frequency sounds originate from large and/or threatening organisms. Cost-benefit analysis suggests that any fights resulting from misses (i.e. not using a "low is large" heuristic) would be of potentially higher cost (i.e. death) than any potential gains in reproductive success garnered from additional mating opportunities secured after combatting an enemy with a lower voice, than the benefits gained by accurately deriving body size from voice alone (see Feinberg, Jones, & Armstrong, in press, for review). Humans are a visually-dominant species, and there is very little selection pressure to very accurately assess the size of other humans from the voice alone, simply because we can see height better than we can hear it. This allows sensory exploitation to take control. If men with lower-pitched voices were able to exploit the sensory bias that low sounds large, threatening, and scary, they would be able to increase their reproductive success, and over the course of generations, drive sex differences in human voice pitch (see Feinberg, Jones, & Armstrong, in press, for review).

Physical vs social dominance

For voice pitch analyses, we found that among men height mediated physical dominance ratings more than social dominance ratings, whereas for women, mediation rates were relatively equal across dominance rating contexts. While physical dominance is thought to be tied to height and strength, both of which are not related to voice pitch, social dominance is additionally influenced by other social factors. For example, voice pitch predicts several objective social dominance outcomes in women and men such as political election results (Gregory Jr & Gallagher, 2002; Klofstad, 2016) and job prestige in highly stereotypically female oriented leadership positions (Anderson & Klofstad, 2012). It is possible that we found stronger mediation among men's voices in the physical dominance condition than in the social dominance condition because social dominance judgements predict real-world outcomes such as political elections (Gregory Jr & Gallagher, 2002; Klofstad, 2016) more than do physical dominance judgements, which are not related to size (Pisanski et al., 2014b; Pisanski et al., 2015) or strength. In other words, social dominance judgements of the voice may be based on a kernel of truth, whereas judgements of physical dominance are driven primarily by bias. Therefore, social dominance judgements are perhaps under less influence from bias from the relationship between voice pitch and perceived body size than are physical dominance judgements.

Men vs women

It is unclear why people are so much worse at estimating women's height than estimating men's height. One idea is that there could be stronger selection pressure to more accurately assess dominance from men's voices than from women's voices due to the differential potential costs of misinterpreting threats from men versus women (Watkins, DeBruine, Feinberg, & Jones, 2013). However, we find evidence of a more parsimonious explanation. Here we found no relationship between voice pitch and height among women. If there is no relationship between pitch and size in women, but people use pitch as a cue to body size, that could explain why residual error rates when estimating women's height are so high. On the other hand, because there was a relatively high correlation between voice pitch and measured height among men, this bias could easily result in more accurate assessment of height – coincidentally rather than causally.

Height mediated the relationship between voice pitch and dominance judgements among women's voices more than it mediated the relationship between voice pitch and dominance judgements among men's voices. This is consistent with the idea that there may be stronger selection pressure to more accurately judge the dominance of men's voices than of women's voices (Watkins et al., 2013). Alternatively, this could potentially be an artefact of the relative strength of association between voice pitch and physical height in our sample. Here, there was no relationship between measured height and voice pitch among women, whereas there was a medium sized effect between voice pitch and height among men. If inaccurate perception of body size from voice pitch drives the mediation of pitch and dominance, then in cases where there is more accuracy, we would expect less mediation. More research is required to determine whether or not this is the case.

How the observed effects might change as a function of socio-cultural factors (e.g., typical mating strategies or gender equality) remains to be investigated. It is possible, for example, that the magnitude of the effects of pitch on dominance perceptions decline as gender equality increases, much as some previous research suggests that the size of sex differences in mate preferences are correlated with the Global Gender Gap Index (Zentner & Mitura, 2012).

Pitch vs Vocal Tract

We found that the relationship between body size and dominance was inconsistently mediated by apparent vocal tract length. This is likely because this is an inappropriate statistical model. Here apparent vocal tract length was not strongly linked to body size. Our effect sizes here are still within the expected range of results (Pisanski et al., 2014b). It should be noted that even though vocal tract length explains a very large proportion of variance in body size, most of this explanatory power is lost when we translate this into formant frequencies. Formant frequencies cannot explain 85% of the variance in body size among same-sex adults. Here it is important to note that even though voice pitch and formants are both tied to the perception of body size (Collins, 2000; Collins & Missing, 2003; Feinberg et al., 2005; Pisanski, Feinberg, Oleszkiewicz, & Sorokowska, 2017; Pisanski et al., 2014b; Pisanski, Oleszkiewicz, & Sorokowska, 2016; Pisanski & Rendall, 2011; Rendall et al., 2007; Smith & Patterson, 2005), and formants are tied to physical height (Pisanski et al., 2014b), these cues are not used in the same way in many mate-choice relevant decisions (Feinberg et al., 2011; Feinberg et al., 2005; Pisanski & Rendall, 2011; Pisanski et al., 2014c). Furthermore, processing of voice pitch and formants take different neural pathways, where voice pitch processing occurs later, and contributes more to bias in perception of size, whereas formant information is used earlier for acoustic size scaling (von Kriegstein, Warren, Ives, Patterson, & Griffiths, 2006), which aids in vowel perception (Turner, Walters, Monaghan, & Patterson, 2009). Although there is an overlap in qualities evoked by the perception of pitch and formants, our results show that these voice qualities cannot be used synonymously in theoretical and experimental contexts (Feinberg et al., 2005).

Bias in pitch perceptions

We found that perceived size mediated the relationship between voice pitch and dominance. Therefore, the perception of dominance is conditional upon perception of height. Perception of height was relatively accurate for men’s voices, but not for women’s voices. Regardless, we found that the proportion of variance in perceived height left unexplained by actual height was the more important component driving perceptions of dominance.

In our sample, there was no relationship between measured body size and voice pitch for women’s voices, and yet voice pitch had a large effect (Cohen 1988) on perceived body size. People continue to perceive a relationship between voice pitch and body size where none exists. If people were actually judging body size, and not using a general heuristic of "low is large", then we would not expect to see people judge women with low-pitched voices as larger than women with high-pitched voices. Other research has shown that people will ascribe large size to voices with pitch outside the range of human vocal production, suggesting that these heuristics are applied widely in human vocal perception (Smith & Patterson, 2005). The tendency to perceive lower-pitch sounds as belonging to larger organisms is also found in 3-month old infants (Pietraszewski, Wertz, Bryant, & Wynn, 2017), so it is seen very early in human development. Additionally, visual experience does not improve the accuracy of size judgments from listening to voices; blind and sighted adults are not different in their accuracy rates when making these assessments (Pisanski et al 2016b; Pisanski et al 2017a). For a recent review on sensory exploitation and evolution of sex differences in voice pitch among humans, see Feinberg, Jones, & Armstrong (in press)

Having a sensory bias to perceive low-pitched sounds as originating from larger sources would be consistent with the idea that large objects emit low frequency noises, and suggests the costs of misses in interpreting a large object as small because of its pitch, outweigh incremental benefits gained from increased accuracy in detecting size among same-sex adults (see Feinberg, Jones, & Armstrong, in press, for review).

Mediation and causality

Our experimental design is correlational in nature. Therefore, results from the mediation tests do not demonstrate causality, which is why they were discussed as “conditional” rather than “causal”. Indeed, mediation results obtained here should be considered “indirect effects”, rather than “causal mediation effects”. Future research could use time-locked sequential events to help establish whether the results we obtained here are causal or not.

SUMMARY

In summary, we found that height mediated the relationship between voice pitch and dominance. These findings were driven by the portion of variance in perceived size that was *inaccurate*. Size mediation of pitch-dominance relationships was stronger among women's voices than men's voices, and stronger for physical dominance judgements than social dominance judgements among men's voices. Collectively, these results suggest that perceptions of dominance are conditional on perception of size. Perception of size, in turn, is likely to be based on general heuristics rather than observational learning. Thus, dominance judgements are conditional upon the same heuristics that low pitch is dominant. Therefore voice pitch is not an honest indicator of physical dominance. Consequently, the evolution of low voice pitch in men may be based on sensory exploitation rather than honest or costly signalling. In absence of any real-world correspondence between voice pitch and determinants of physical dominance, theories of the evolution of low voice pitch in men cannot rely on honest signalling or good genes explanations of sexual selection. Our results suggest that dominance ratings may be the result of a bias to perceive low pitch as large, rather than the result of honest communication. Here, sensory exploitation of the bias to attribute large size to low pitched voices explains that a pre-existing bias that "low is large" predated the evolution of low voice pitch in men. Those men that were able to exploit this relationship by using a low-pitched voice to secure their positions as strong group leaders may have enjoyed the highest reproductive success. In turn, this can select for lower-pitched voices in men that sound more dominant – even in the absence of a real-world correspondence between voice pitch and physical markers of dominance (see Feinberg, Jones, & Armstrong, in press, for review).

References

Anderson, R. C., & Klofstad, C. A. (2012). Preference for leaders with masculine voices holds in the case of feminine leadership roles. *PloS One, 7*(12), e51216. https://doi.org/10.1371/journal.pone.0051216

Andersson, M. (1994). *Sexual selection*. New Jersey: Princeton University Press.

Bakker, M., Hartgerink, C. H. J., Wicherts, J. M., & Maas, H. L. J. van der. (2016). Researchers' intuitions about power in psychological research. *Psychological Science*, *27*(8), 1069–1077. https://doi.org/10.1177/0956797616647519

Barr, D. J. (2013). Random effects structure for testing interactions in linear mixed-effects models. Frontiers in Psychology, 4, 328. https://doi.org/10.3389/fpsyg.2013.00328

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. Journal of Memory and Language, 68(3), 255-278. https://doi.org/10.1016/j.jml.2012.11.001

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models usng lme4. *Journal of Statistical Software, 67*(1), 1-48.

Boersma, P., & Weenink, D. (2013). Praat: Doing phonetics by computer [Computer program]. Retrieved from: http://www.fon.hum.uva.nl/praat/.

Borkowska, B., & Pawlowski, B. (2011). Female voice frequency in the context of dominance and attractiveness perception. *Animal Behaviour*, *82*(1), 55–59. https://doi.org/10.1016/j.anbehav.2011.03.024

Bowling, D. L., Garcia, M., Dunn, J. C., Ruprecht, R., Stewart, A., Frommolt, K. H., & Fitch, W. T. (2017). Body size and vocalization in primates and carnivores. *Scientific Reports*, *7*. https://doi.org/10.1038/srep41070

Bruckert, L., Liénard, J. S., Lacroix, A., Kreutzer, M., & Leboucher, G. (2006). Women use voice parameters to assess men's characteristics. *Proceedings of the Royal Society Biological Sciences Series B*, *273*(1582), 83–89. https://doi.org/10.1098/rspb.2005.3265

Cohen J. (1988). *Statistical power analysis for the behavioral sciences.* New York, NY: Routledge Academic

Collins, S. A. (2000). Men’s voices and women’s choices. *Animal Behaviour*, *60*(6), 773–780. https://doi.org/10.1006/anbe.2000.1523

Collins, S. A., & Missing, C. (2003). Vocal and visual attractiveness are related in women. *Animal Behaviour*, *65*, 997–1004. https://doi.org/10.1006/anbe.2003.2123

Cowan, M. L., Watkins, C. D., Fraccaro, P. J., Feinberg, D. R., & Little, A. C. (2015). It’s the way he tells them (and who is listening): Men’s dominance is positively correlated with their preference for jokes told by dominant-sounding men. *Evolution and Human Behavior*. *37*(2), 97–104 https://doi.org/10.1016/j.evolhumbehav.2015.09.002

Darwin, C. (2004). The Descent of man. 1871. *Reprinted in Penguin Classics Series*.

Davies, N. B., & Halliday, T. R. (1978). Deep croaks and fighting assessments in toads *Bufo-bufo. Nature*, *274*(5672), 683–685. https://doi.org/10.1038/274683a0

Dawkins, M. S., & Guilford, T. (1996). Sensory bias and the adaptiveness of female choice. *The American Naturalist*, *148*(5), 937–942.

Doll, L. M., Hill, A. K., Rotella, M. A., Cárdenas, R. A., Welling, L. L. M., Wheatley, J. R., & Puts, D. A. (2014). How Well Do Men’s Faces and Voices Index Mate Quality and Dominance? *Human Nature-an Interdisciplinary Biosocial Perspective*, *25*(2), 200–212. https://doi.org/10.1007/s12110-014-9194-3

Fahey, T. D., Rolph, R., Moungmee, P., Nagel, J., & Mortara, S. (1976). Serum testosterone, body composition, and strength of young adults. *Medicine and Science in Sports*, *8*(1), 31–34.

Favaro, L., Gamba, M., Gili, C., & Pessani, D. (2017). Acoustic correlates of body size and individual identity in banded penguins. *PLOS ONE*, *12*(2), e0170001. https://doi.org/10.1371/journal.pone.0170001

Feinberg, D., Jones, B., Armstrong, M. (in press). Sensory Exploitation, Sexual Dimorphism, and Human Voice Pitch. *Trends in Ecology & Evolution.* https://doi.org/10.1016/j.tree.2018.09.007

Feinberg, D., Jones, B., DeBruine, L., O’Connor, J., Tigue, C., & Borak, D. (2011). Integrating fundamental and formant frequencies in women’s preferences for men’s voices. *Behavioral Ecology*, *22*(6), 1320–1325. https://doi.org/10.1093/beheco/arr134

Feinberg, D., Jones, B., Law Smith, M., Moore, F. R., DeBruine, L., Cornwell, R., Hillier, S., & Perrett, D. (2006). Menstrual cycle, trait estrogen level, and masculinity preferences in the human voice. *Hormones and Behavior*, *49*(2), 215–222. https://doi.org/10.1016/j.yhbeh.2005.07.004

Feinberg, D. R. (2008). Are human faces and voices ornaments signaling common underlying cues to mate value? *Evolutionary Anthropology: Issues, News, and Reviews*, *17*(2), 112–118. https://doi.org/10.1002/evan.20166

Feinberg, D. R., Jones, B. C., Little, A. C., Burt, D. M., & Perrett, D. I. (2005). Manipulations of fundamental and formant frequencies influence the attractiveness of human male voices. *Animal Behaviour*, *69*(3), 561–568. https://doi.org/10.1016/j.anbehav.2004.06.012

Fitch, W. T. (1997). Vocal tract length and formant frequency dispersion correlate with body size in rhesus macaques. *Journal of the Acoustical Society of America*, *102*(2 Pt 1), 1213–1222. https://doi.org/10.1121/1.421048

Fitch, W. T., & Giedd, J. (1999). Morphology and development of the human vocal tract: A study using magnetic resonance imaging. *Journal of the Acoustical Society of America*, *106*(3), 1511–1522. https://doi.org/10.1121/1.427148

Fouquet, M., Pisanski, K., Mathevon, N., & Reby, D. (2016). Seven and up: individual differences in male voice fundamental frequency emerge before puberty and remain stable throughout adulthood. *Royal Society Open Science*, *3*(10), 160395. https://doi.org/10.1098/rsos.160395

González, J. (2003). Estimation of speakers' weight and height from speech: a re-analysis of data from multiple studies by Lass and colleagues. *Perceptual and Motor Skills*, *96*(1), 297–304. https://doi.org/ 10.2466/PMS.96.1.297-304

Gregory Jr, S. W., & Gallagher, T. J. (2002). Spectral analysis of candidates' nonverbal vocal communication: Predicting US presidential election outcomes. *Social Psychology Quarterly*, 298–308. https://doi.org/10.2307/3090125

Griggs, R. C., Kingston, W., Jozefowicz, R. F., Herr, B. E., Forbes, G., & Halliday, D. (1989). Effect of testosterone on muscle mass and muscle protein synthesis. *Journal of Applied Physiology*, *66*(1), 498–503. https://doi.org/10.1152/jappl.1989.66.1.498

Han, C. Y., Kandrik, M., Hahn, A. C., Fisher, C. I., Feinberg, D. R., Holzleitner, I. J., DeBruine, L.M., & Jones, B. C. (2017). Interrelationships among men's threat potential, facial dominance, and vocal dominance. *Evolutionary Psychology*, *15*(1). https://doi.org/10.1177/1474704917697332

Harries, M., Hawkins, S., Hacking, J., & Hughes, I. (1998). Changes in the male voice at puberty. Vocal fold length and its relationship to the fundamental frequency of the voice. *Journal of Laryngology and Otology*, *112*(5), 451–454. https://doi.org/10.1017/S0022215100140757

Hauser, M. D. (1993). The Evolution of Nonhuman Primate Vocalizations: Effects of Phylogeny, Body Weight, and Social Context. *The American Naturalist*, *142*(3), 528–542. https://doi.org/10.1086/285553

Hodges-Simeon, C. R., Gaulin, S. J., & Puts, D. A. (2011). Voice correlates of mating success in men: examining "contests" versus "mate choice" modes of sexual selection. *Archives of Sexual Behavior*, *40*(3), 551–557. https://doi.org/10.1007/s10508-010-9625-0

Johnstone, R. A. (1995). Sexual Selection, Honest Advertisement and the Handicap Principle: Reviewing the Evidence. *Biological Reviews*, *70*(1), 1–65. https://doi.org/10.1111/j.1469-185X.1995.tb01439.x

Jones, B. C., Feinberg, D. R., DeBruine, L. M., Little, A. C., & Vukovic, J. (2010). A domain-specific opposite-sex bias in human preferences for manipulated voice pitch. *Animal Behaviour*, *79*(1), 57–62. https://doi.org/10.1016/j.anbehav.2009.10.003

Kenny, D. A. (2017). MedPower: An interactive tool for the estimation of power in tests of mediation [Computer software]. Available from https://davidakenny.shinyapps.io/PowerMed/.

Klofstad, C. A. (2016). Candidate Voice Pitch Influences Election Outcomes. *Political Psychology*, *37*(5), 725–738. https://doi.org/10.1111/pops.12280

Klofstad, C. A., Anderson, R. C., & Peters, S. (2012). Sounds like a winner: voice pitch influences perception of leadership capacity in both men and women. *Proceedings of the Royal Society B-Biological Sciences*, *279*(1738), 2698–2704. https://doi.org/10.1098/rspb.2012.0311

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2015). lmerTest: Tests for random and fixed effects for linear mexed effect models. Retrieved from https://CRAN.R-project.org/package=lmerTest

Martin, K., Tucker, M. A., & Rogers, T. L., 2017. Does size matter? Examining the drivers of mammalian vocalizations. *Evolution*, *71(2)*, 249–260. https://doi.org/10.1111/evo.1312

Maynard Smith, J., & Price, G. R. (1973). The logic of animal conflict. *Nature*, *246*(5427), 15–18.

Mayew, W. J., Parsons, C. A., & Venkatachalam, M. (2013). Voice pitch and the labor market success of male chief executive officers. *Evolution and Human Behavior*, *34*(4), 243–248. https://doi.org/10.1016/j.evolhumbehav.2013.03.001

Mazur, A., Halpern, C., & Udry, J. R., 1994. Dominant looking male teenagers copulate earlier. *Ethology and Sociobiology*. *15*(2), 87–94. https://doi.org/10.1016/0162-3095(94)90019-1

Owings, D. H., & Morton, E. S. (1998). *Animal vocal communication: a new approach*. Cambridge University Press.

Pavela Banai, I., Banai, B., & Bovan, K. (2017). Vocal characteristics of presidential candidates can predict the outcome of actual elections. *Evolution and Human Behavior*, *38*(3), 309–314. https://doi.org/10.1016/j.evolhumbehav.2016.10.012

Peirce, J. W., 2007. PsychoPy - Psychophysics software in Python. *Journal of Neuroscience Methods, 162*(1-2), 8-13. https://doi.org/10.1016/j.jneumeth.2006.11.017

Pietraszewski, D., Wertz, A. E., Bryant, G. A., & Wynn, K., 2017. Three-month-old human infants use vocal cues of body size. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1856), 20170656. https://doi.org/10.1098/rspb.2017.0656

Pisanski, K., Feinberg, D., Oleszkiewicz, A., & Sorokowska, A. (2017). Voice cues are used in a similar way by blind and sighted adults when assessing women's body size. *Scientific Reports*, *7*. 10329. https://doi.org/10.1038/s41598-017-10470-3

Pisanski, K., Fink, B., O'Connor, J. J., DeBruine, L., Röder, S., & Feinberg, D. R. (2015). Voice parameters predict sex-specific body morphology in men and women. *Animal Behaviour*. https://doi.org/10.1016/j.anbehav.2015.11.008

Pisanski, K., Fraccaro, P. J., Tigue, C. C., O'Connor, J. J. M., & Feinberg, D. R. (2014). Return to Oz: Voice Pitch Facilitates Assessments of Men's Body Size. *Journal of Experimental Psychology-Human Perception and Performance*, *40*(4), 1316–1331. https://doi.org/10.1037/a0036956

Pisanski, K., Fraccaro, P. J., Tigue, C. C., O'Connor, J. J., Röder, S., Andrews, P. W., Fink, B., DeBruine, L. M., Jones, B. C., & Feinberg, D. R. (2014). Vocal indicators of body size in men and women: a meta-analysis. *Animal Behaviour*, *95*, 89–99. https://doi.org/10.1016/j.anbehav.2014.06.011

Pisanski, K., Hahn, A. C., Fisher, C. I., DeBruine, L. M., Feinberg, D. R., & Jones, B. C. (2014). Changes in salivary estradiol predict changes in women's preferences for vocal masculinity. *Hormones and Behavior, 66*(3), 493–497. https://doi.org/10.1016/j.yhbeh.2014.07.006

Pisanski, K., Isenstein, S. G., Montano, K. J., O'Connor, J. J., & Feinberg, D. R. (2017). Low is large: spatial location and pitch interact in voice-based body size estimation. *Attention, Perception, & Psychophysics*, *79*(4), 1239–1251. https://doi.org/10.3758/s13414-016-1273-6

Pisanski, K., Mishra, S., & Rendall, D., 2012. The evolved psychology of voice: evaluating interrelationships in listeners' assessments of the size, masculinity, and attractiveness of unseen speakers. *Evolution and Human Behavior*, *33*(5), 509–519. https://doi.org/10.1016/j.evolhumbehav.2012.01.004

Pisanski, K., Mora, E. C., Pisanski, A., Reby, D., Sorokowski, P., Frackowiak, T., & Feinberg, D. R. (2016). Volitional exaggeration of body size through fundamental and formant frequency modulation in humans. *Scientific Reports*, *6*, 34389. https://doi.org/10.1038/srep34389

Pisanski, K., Oleszkiewicz, A., & Sorokowska, A. (2016). Can blind persons accurately assess body size from the voice? *Biology Letters*, *12*(4). https://doi.org/10.1098/rsbl.2016.0063

Pisanski, K., & Rendall, D. (2011). The prioritization of voice fundamental frequency or formants in listeners' assessments of speaker size, masculinity, and attractiveness. *Journal of the Acoustical Society of America*, *129*(4), 2201–2212. https://doi.org/10.1121/1.3552866

Puts, D. (2016). Human sexual selection. *Current Opinion in Psychology*, *7*, 28–32. https://doi.org/10.1016/j.copsyc.2015.07.011

Puts, D. A. (2010). Beauty and the beast: mechanisms of sexual selection in humans. *Evolution and Human Behavior*, *31*(3), 157–175. https://doi.org/10.1016/j.evolhumbehav.2010.02.005

Puts, D. A., Apicella, C. L., & Cárdenas, R. A. (2012). Masculine voices signal men's threat potential in forager and industrial societies. *Proceedings of the Royal Society B-Biological Sciences*, *279*(1728), 601–609. https://doi.org/10.1098/rspb.2011.0829

Puts, D. A., Gaulin, S. J., & Verdolini, K. (2006). Dominance and the evolution of sexual dimorphism in human voice pitch. *Evolution and Human Behavior*, *27*(4), 283–296. https://doi.org/10.1016/j.evolhumbehav.2005.11.003

Puts, D. A., Hill, A. K., Bailey, D. H., Walker, R. S., Rendall, D., Wheatley, J. R., Welling, L. L. M., Dawood, K., Cárdenas, R., Burriss, R. P., Jablonski, N. G., Shriver, M. D., Weiss, D., Lameira, A. R., Apicella, C. L., Owren, M. J., Barelli, C., Glenn, M. E., Ramos-Fernandez, G. (2016). Sexual selection on male vocal fundamental frequency in humans and other anthropoids. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1829), 20152830. https://doi.org/10.1098/rspb.2015.2830

Puts, D. A., Hodges, C. R., Cárdenas, R. A., & Gaulin, S. J. C. (2007). Men's voices as dominance signals: vocal fundamental and formant frequencies influence dominance attributions among men. *Evolution and Human Behavior*, *28*(5), 340–344. https://doi.org/10.1016/j.evolhumbehav.2007.05.002

Reby, D., & McComb, K. (2003). Anatomical constraints generate honesty: acoustic cues to age and weight in the roars of red deer stags. *Animal Behaviour, 65*(3), 519–530. https://doi.org/10.1006/anbe.2003.2078

Rendall, D., Vokey, J. R., & Nemeth, C. (2007). Lifting the curtain on the Wizard of Oz: biased voice-based impressions of speaker size. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(5), 1208–1219. https://doi.org/10.1037/0096-1523.33.5.1208

Ryan, M. J., & Keddy-Hector, A. (1992). Directional Patterns of Female Mate Choice and the Role of Sensory Biases. *The American Naturalist*, *139*, S4–S35.

Sell, A., Bryant, G. A., Cosmides, L., Tooby, J., Sznycer, D., von Rueden, C., Krauss, A., Gurven, M. (2010). Adaptations in humans for assessing physical strength from the voice. *Proceedings of the Royal Society B-Biological Sciences*, *277*(1699), 3509–3518. https://doi.org/10.1098/rspb.2010.0769

Smith, D. R., & Patterson, R. D. (2005). The interaction of glottal-pulse rate and vocal-tract length in judgements of speaker size, sex, and age. *Journal of the Acoustical Society of America*, *118*(5), 3177–3186. https:// doi.org/10.1121/1.2047107

Smith, K. M., Olkhov, Y. M., Puts, D. A., Apicella, C.L., 2017. Hadza men with lower voice pitch have a better hunting reputation. *Evolutionary Psychology, 15*(4), 1474-7049. https://doi.org/10.1177/1474704917740466

Sulter, A. M., Miller, D. G., Wolf, R. F., Schutte, H. K., Wit, H. P., & Mooyaart, E. L. (1992). On the relation between the dimensions and resonance characteristics of the vocal tract: a study with MRI. *Magnetic Resonance Imaging*, *10*(3), 365–373. https://doi.org/10.1016/0730-725X(92)90507-V

Tigue, C. C., Borak, D. J., O'Connor, J. J., Schandl, C., & Feinberg, D. R. (2012). Voice pitch influences voting behavior. *Evolution and Human Behavior*, *33*(3), 210–216. https://doi.org/10.1016/j.evolhumbehav.2011.09.004

Tingley, D., Yamamoto, T., Hirose, K., Keele, L., & Imai, K. (2014). mediation: R package for causal mediation analysis. *Journal of Statistical Software, 59*(5), 1-38.

Titze, I. R. (1994). *Principles of voice production*. Englewood Cliffs, NJ.: Prentice Hall.

Tremblay, R. E., Schaal, B., Boulerice, B., Arseneault, L., Soussignan, R. G., Paquette, D., & Laurent, D. (1998). Testosterone, physical aggression, dominance, and physical development in early adolescence. *International Journal of Behavioral Development*, *22*(4), 753–777. https://doi.org/10.1080/016502598384153

Trivers, R. L. (1976). Sexual selection and resource-accruing abilities in Anolis garmani. *Evolution*, *30*(2), 253–269.

Turner, R. E., Walters, T. C., Monaghan, J. J., & Patterson, R. D. (2009). A statistical, formant-pattern model for segregating vowel type and vocal-tract length in developmental formant data. *The Journal of the Acoustical Society of America*, *125*(4), 2374–2386. https://doi.org/10.1121/1.3079772

van Dommelen, W. A., & Moxness, B. H. (1995). Acoustic parameters in speaker height and weight identification: sex-specific behaviour. *Language and Speech*, *38*(3), 267–287. doi:10.1177/002383099503800304

von Kriegstein, K., Warren, J. D., Ives, D. T., Patterson, R. D., & Griffiths, T. D. (2006). Processing the acoustic effect of size in speech sounds. *NeuroImage*, *32*(1), 368–375. https://doi.org/10.1016/j.neuroimage.2006.02.045

Vukovic, J., Jones, B. C., Feinberg, D. R., DeBruine, L. M., Smith, F. G., Welling, L. L., & Little, A. C. (2011). Variation in perceptions of physical dominance and trustworthiness predicts individual differences in the effect of relationship context on women's preferences for masculine pitch in men's voices. *British Journal of Psychology*, *102*(1), 37–48. https://doi.org/10.1348/000712610X498750

Watkins, C. D., Debruine, L. M., Feinberg, D. R., & Jones, B. C. (2013). A sex difference in the context-sensitivity of dominance perceptions. *Evolution and Human Behavior*, *34*(5), 366–372. https://doi.org/10.1016/j.evolhumbehav.2013.06.004

Zentner, M., & Mitura, K. (2012). Stepping Out of the Caveman's Shadow: Nations' Gender Gap Predicts Degree of Sex Differentiation in Mate Preferences. *Psychological Science*, *23*(10), 1176–1185. https://doi.org/10.1177/0956797612441004

Table 1: Number and Age of Participants

Rating Attribute	*Gender of Raters*	*N*	*Mean (S.D.) Age*
	Female Voices		
Perceived Height	Women	56	18.7 (1.33)
	Men	33	18.6 (0.87)
Perceived Physical Dominance	Women	53	18.5 (1.44)
	Men	41	18.7 (1.30)
Perceived Social Dominance	Women	52	18.9 (2.21)
	Men	38	18.9 (1.32)
	Male Voices		

Perceived Height	Women	54	18.7 (1.33)
	Men	31	19.1 (1.13)
Perceived Physical Dominance	Women	55	19.1 (2.39)
	Men	35	18.8 (1.30)
Perceived Social Dominance	Women	52	19.1 (1.93)
	Men	33	18.9 (1.29)

Figure 1: Mediation model showing predictor variable (voice pitch), mediating variables (height perceptions) and outcome variables (dominance perceptions).

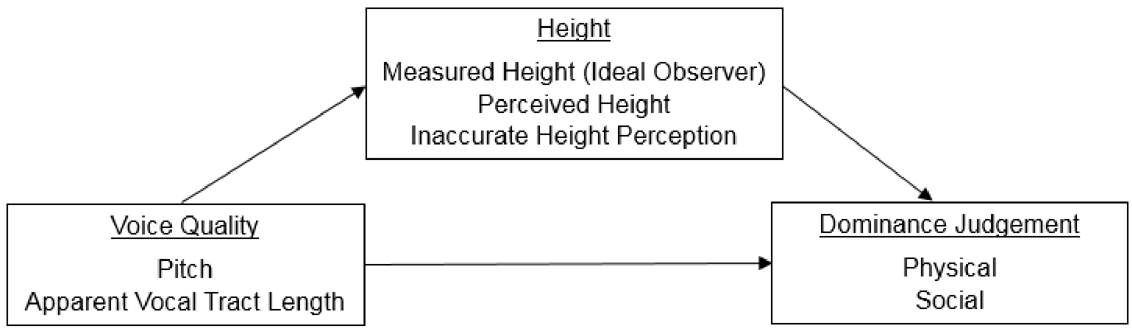
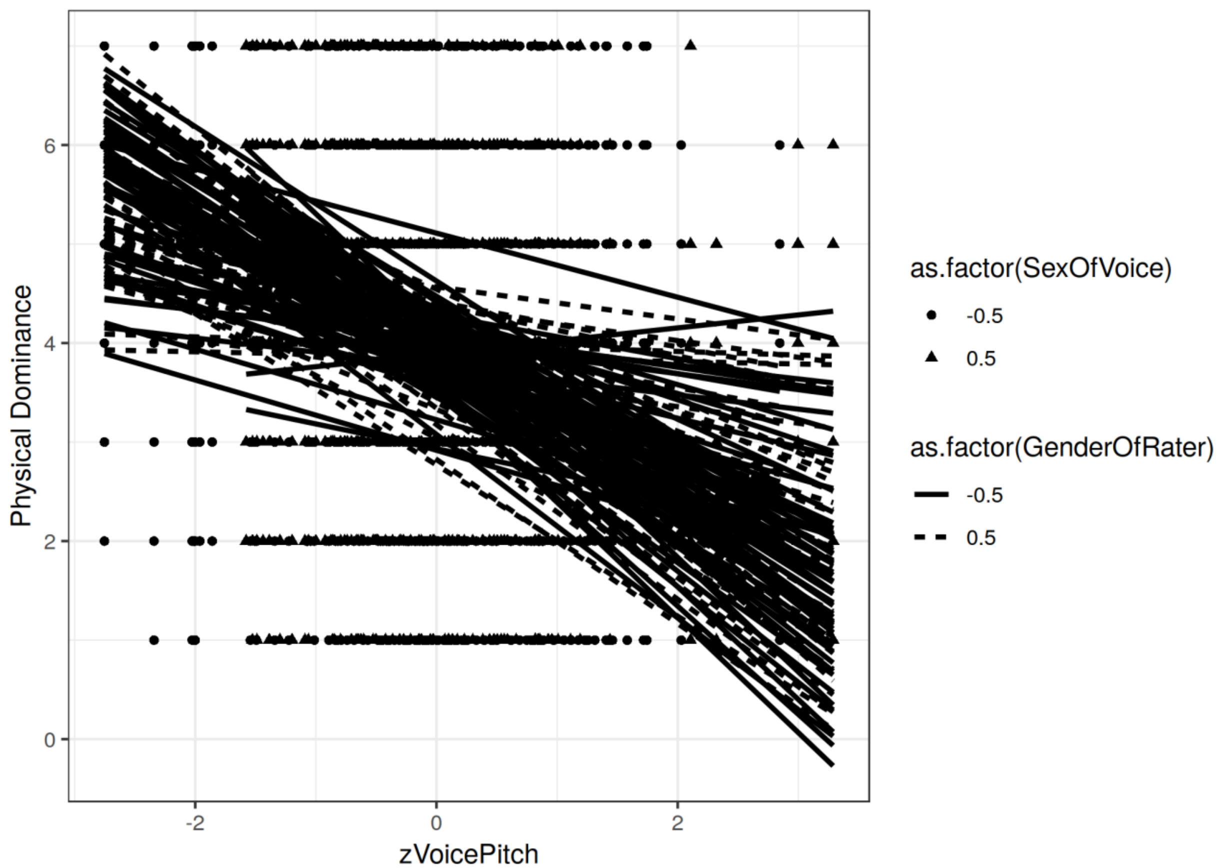


Figure 2 – The relationship between voice pitch and perceived physical dominance. Each line represents a participant’s ratings. -0.5 represents data from cisgender women, 0.5 represents data from cisgender men.


Physical Dominance
zVoicePitch
0
2
4
6
-2
0
2
as.factor(SexOfVoice)
-0.5
0.5
as.factor(GenderOfRater)
-0.5
0.5